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A method of determining common stray light for ruled gratings and other spectral apparatus

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With 13 figures in the text

Introduction

The main factors to be considered in judging the quality of spectroscopic instruments are the optical properties of the transparent and reflecting details, the resolving power, dispersion, purity of the spectrum, i. e. freedom from stray light, etc.

Stray light can have more or less influence on measurements made with the instrument. For spectrometers and monochromators, which are used for measurements of absorption and transmission, a small amount of stray light may completely disturb the results.

In prism instruments light is scattered in the transparent medium of prisms and lenses and is reflected at surfaces, diaphragms and covers. For gratings the circumstances are more difficult to survey. Different opinions concerning whether grating or prism is the better with regard to stray light have also appeared. According to Harrison, Loof and Loofbourow (1), most of the concave grating spectrographs with an original grating have less stray light than prism instruments, while instruments with replica gratings are worse than prism instruments. The stray light from a grating ruled on aluminium is considerably less than from a speculum grating, because its surface is less grainy. The reflecting power of a speculum grating can be increased by evaporating aluminium on it, as is well known, but the stray light is not decreased.

Cary and Beckman (2) made comparative measurements on gratings and prisms and found that prisms are superior to gratings with regard to stray light. They did not find any grating with less than 5 per cent stray light within any part of the investigated wavelength range, but it is not clear how the measurements were evaluated.

Measurements of stray light on a spectrophotometer were made by the constructors Sheard and States (3). They used a concave replica grating in an Eagle mounting. The stray light was measured by comparing transmission values, measured with the instrument, for a number of filters with corresponding values, given by the National Bureau of Standards. The maximum stray light is stated to be 1 per cent, which also contains light diffused by the internal surfaces of the instrument.

The present investigation concerns the stray light originating at the surface of the grating. Its origin is due to different phenomena (4). Small errors in the movement of the diamond in ruling a groove give rise to the so-called foot light, the strength of which in conformity with what applies to the intensity of the Rowland ghosts, is proportional to the square of the order. Another cause is reflexion from irregularities in the grooves of the grating and its surface. The intensity of this stray light varies with the position. If the irregularities were quite random, this stray light ought to be strongest in the zero-order reflexion and decrease in the higher orders, cf. HARTER (5) and BARKAS (6). This stray light generally occurs more or less concentrated and mostly in the neighbourhood of and in strong spectra. An inevitable contribution to the stray light is due to the bi-maxima produced by interference.

Measurements of the stray light can be made in different ways, but the general methods for optical instruments are not well applicable, because one has to measure in a spectrum. Here we have used a method, proposed and earlier shortly described by one of the authors (7), with the special aim of obtaining an accuracy suitable to the purest spectra.

Measuring method

The measurements were made in a spectrometer according to PASCHEN-RUNGE. As light source a tungsten lamp was used, and a continuous spectrum is obtained. The UV-radiation below 3600 A is absorbed by a filter. Between the lamp and the entrance slit a didymium glass is placed, which has several sharp absorption bands, the most marked at 5825 A. The transmission values of the glass are known. In the first order spectrum a multiplier photocell is placed in this band, and measurements of the light intensity with and without didymium glass in the light beam are made. From these registered spectral distribution values and the known transmission values, the stray light can be calculated. In order to find the spectral distribution of the stray light a trichromatic method is used, in which the light intensity is measured with filters inserted to divide the incident light into three parts, blue, green, and red. The measurements in the yellow region were extended to the range around 3150 A by moving the photocell to this range.

The results obtained by this method using a continuous spectrum lamp may, as will be indicated in the end of the article, to some extent be applied to sources giving line spectra. In line spectra with relatively few lines, the stray light is usually negligible. The circumstances become different in line-rich spectra and in continuous spectra, where the contribution from many or all wave lengths must be summed up. An extension of the investigation to line spectra cases will be made. The method with some modifications is meant to be applied to prism instruments.

Experimental arrangement and details of the equipment

On the Rowland circle (Fig. 1) the entrance slit S and the grating G in an adjustable support are fixed. The photocell housing P, mounted on the optical bench OP, is controlled by a bar B, so that the slit plane in front of the

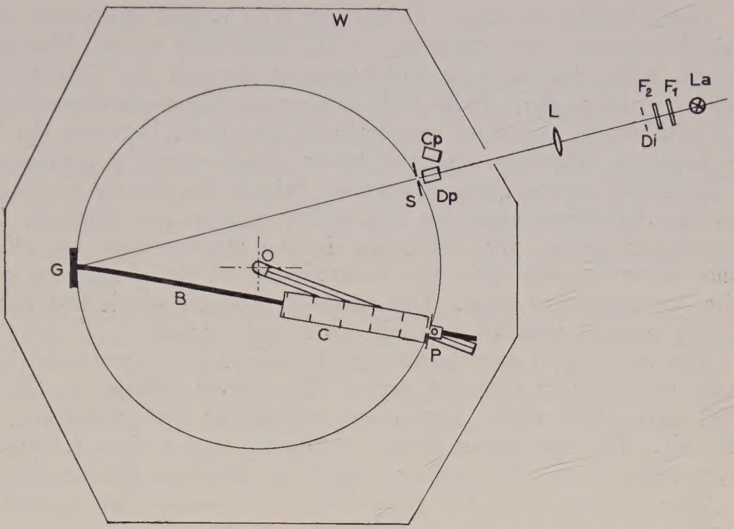

Fig. 1. Schematic view of the apparatus. La lamp, F_1 ultraviolet filter, F_2 holder for the colour filters, Di diaphragm, L lens, Dp didymium prism, Cp compensating prism, S entrance slit, G concave grating with its Rowland circle, P photomultiplier tube with the exit slit, C case with diaphragms, B bar, O center about which the optical bench turns, W wall covered with velvet.

photocell is always at right angles to the direction of the rays from the grating. Thus the light will always reach the photocell in the same manner.

The lamp La is a tungsten band lamp, Philips E 27, 6 V, 100 W. Its temperature as a function of the voltage was determined by means of an optical micro-pyrometer. The lamp voltage was controlled so that the lamp at all measurements had a colour temperature of 2 800° K.

In order to avoid any influence on the measurements from the radiation in the UV region, the UV radiation was absorbed by a filter F_1, consisting of a gelatine filter of β-naphtoldisulphonic acid with a concentration of 10 g/m^2 between two glass plates (corresponding to Kodak Wratten No. 1). The absorption curve is shown in Fig. 2.

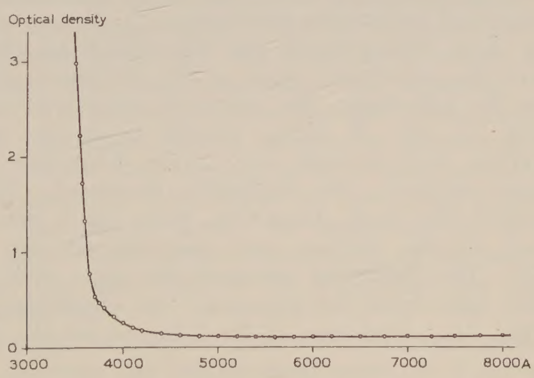

Fig. 2. Absorption curve of the ultraviolet filter.

Immediately in front of the slit S is placed the prism of didymium glass, which absorbs the radiation in the measured range. Measurements should be made with the incident light passing through the didymium glass prism and without the prism. To be able to compare the measurements without corrections in both cases, the same geometrical light path between the lamp and photocell is required. Therefore, for the latter measurement a compensating prism Cp of borosilicate crown glass is inserted, which has nearly the same refractive index as the didymium glass for the yellow sodium line 5893 A. By using the compensating prism, the reflexions in the glass surface are eliminated, and thus the measurements give the transmission of the didymium glass in relation to the compensating glass. The surfaces through which the light passes are accurately ground parallel to each other and lapped.

The anode and dynode voltages to the photocell were obtained from a rectifier and stabilizer of common type. The output voltage can be adjusted between 600 and 1200 volts. The noise voltage at 1000 volts and full load is about 10 mV. The stabilizing factor is slightly better than 1:100. No influence from variations in the line voltage could be observed during the measurements.

The current from the photocell was measured by a galvanometer provided with a variable shunting circuit, made so that its external impedance was always constant. The galvanometer was a part of the circuit, and thus the same damping was always obtained. Full deflection (800 mm) corresponds to 2.6, 26 and 260 μA. Only the two most sensitive ranges were used, and thus the photocell current never exceeded 26 μA.

Both types of photomultiplier, 931—A and 1P22 were used. As they have somewhat different spectral sensitivities, a good check of the accuracy of the method is obtained. Having found this, the further measurements were made with a 931—A, this cell being the most common.

The measurements were intended to determine only the stray light which originates from the ruled surface of the grating. By various means we succeeded in avoiding errors due to light reflected from internal surfaces of the instrument. The solid angle of the entering light is kept to a minimum by forming an image of a diaphragm Di on the ruled area of the grating by means of the lens L, which is also used for focussing the light source on the slit. The walls of the apparatus were made of velvet in order to eliminate the stray light which might be reflected from them. Moreover the photocell housing was provided with a long box C, which contained six diaphragms with rectangular orifices, of successively decreasing dimensions.

With these arrangements the following tests were made. The photocell was placed in the absorption range of the didymium glass. With the compensating glass in the light-beam, the photocell current was adjusted to a maximum value of about 15 μA. A white, smooth paper was put around the grating. The glass prisms were changed, and as the didymium glass absorbed all the monochromatic radiation, the deflection decreased. The white paper, which ought to increase the most dangerous stray light, coming from the immediate surroundings of the grating, was removed, and the galvanometer deflection was observed. The deflection remained the same with and without the paper. Thus the stray light from the apparatus was eliminated to such an extent that any remaining stray light was of no influence on the measurements.

Measurements

The measurements have been made on four different gratings, one American replica, manufactured by The Perkin Elmer Corp. with 576 grooves/mm, and on three originals, ruled in Prof. Siegbahn's machines. Of these one was ruled in the larger machine (marked No. 172037). This grating has 720 grooves/mm and is of the common type with symmetrical grooves, like the American grating. The other two gratings were marked with the numbers 157673 and 157674, respectively. They were ruled in the smaller machine, have 576 grooves/mm, and are of the blazed type (8, 9).

The amount of stray light can be stated in different ways, either in relation to the energy radiating towards the surface of the grating or in relation to the monochromatic energy contained in the spectrum. The latter definition corresponds to the noise ratio used in electronics. For the spectroscopist, too, this is the most interesting, since it states directly the influence to be expected from stray light. The dependence of the stray light on the angle of incidence was also determined. Measurements have been made on a spectrum of the first order, and the movement of the spectrum with varied angle of incidence was followed. For each angle of incidence the spectrum is calibrated in wavelengths by means of a mercury lamp, using the photocell as receiver.

In order to pass from this measurement of the stray light ratio influence to the other, where the stray light is stated in relation to the incident energy, it is necessary to know how the energy in spectra of the first order varies with the angle of incidence. In the new blazed gratings there exists a certain preferred direction for the maximum energy, owing to reflexion connected with the diffraction. It can be shown that for small incident and exit angles, the angular difference between the diffracted and refracted rays vary only slightly. The blaze effect and therefore the whole energy ought thus to be fairly constant for moderate great angles of incidence. Of geometrical reasons to be taken into consideration later, as astigmatism and mirror image formation, the stray light noise ratio, however, can vary considerably with the angle of incidence.

The measurements were made as absorption measurements for didymium glass, point by point, in the range between 5600–6200 A. According to the arrangements Fig. 1, all values are obtained for constant $d\lambda$. Absorption and transmission curves were obtained for the didymium glass according to Figs. 3 and 4.

The fully drawn curves are the real transmission and absorption curves, which were measured in a Beckman spectrophotometer. For the measurements on the gratings, a prism with a thickness of 45 mm was used, which means that all monochromatic radiation within the measuring range was absorbed. Optical density was between 4 and 6. The measurements in the spectrophotometer were made on a combination, i. e. didymium glass in relation to borosilicate crown glass with a thickness of 15 mm cut from the same piece of glass, as the thicker prisms did not fit into the instrument. The curves for the 45 mm glasses were obtained by multiplying by the proper factor. By measuring on a thinner combination than the one used, which gives lower values of the absorption, one has the advantage that the stray light of the instrument has negligible influence on the final absorption curve.

The measurements were checked at frequent intervals by measuring the same curve twice. The difference between the curves never exceeded 3 per cent of

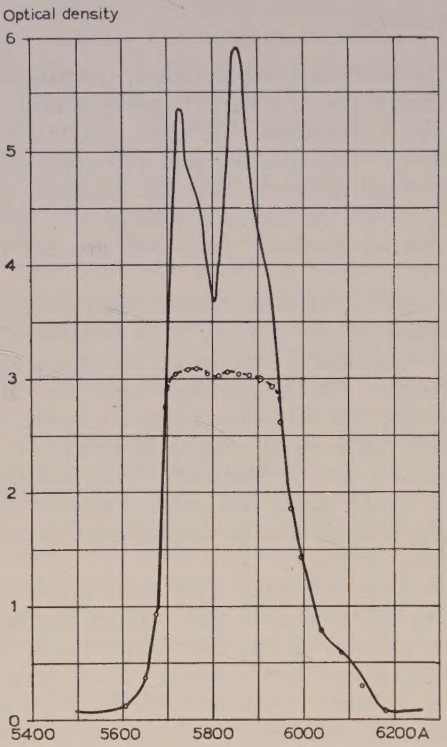

Fig. 3. Density curve of the didymium prism. The dotted line gives an example of a series of measurements in the presence of stray light.

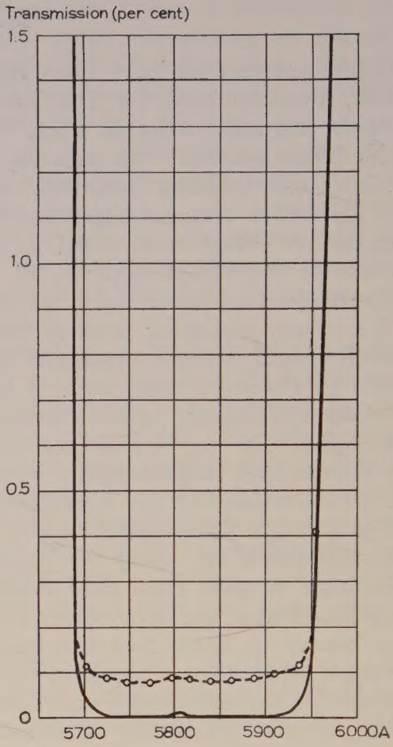

Fig. 4. Transmission curves corresponding to Fig. 3.

the transmission values. This error contains random variations owing to variations in the voltage of the photocell, the surfaces of the prisms, which were lapped between the measurements, their position, etc. It is impossible to attribute the errors to their different sources. The greatest contribution probably comes from the glass prisms.

The measurements in the range around 3150 A were made in such a way that the photocell current was measured with the didymium glass in the light beam for a number of points in the range 5825 A. With unchanged voltages, etc., the photocell was then moved to the lower range, and the same measurements were made for a few points in this range. To obtain sufficient accuracy for this measurement, the same surface of the photocell must be used in both cases (10), which is secured by the bar B, Fig. 1.

It is necessary to make a rough investigation regarding the spectral composition of the stray light. Three filters, Schott VG1, RG2, and BG12, with transmission curves according to Fig. 5, were introduced into the light beam. The deflection was determined at the above mentioned points with the different filters, and curves according to Fig. 6 were obtained for both ranges of the investigated grating.

The accuracy of these measurements is somewhat less than the primary measurements of the stray light. Here deviations may occur due to changes in

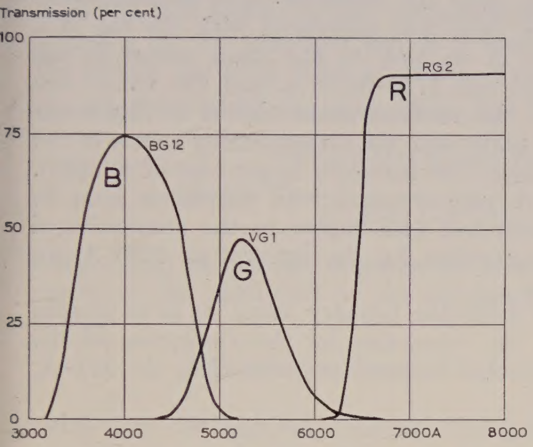

Fig. 5. Transmission curves of the three filters used.

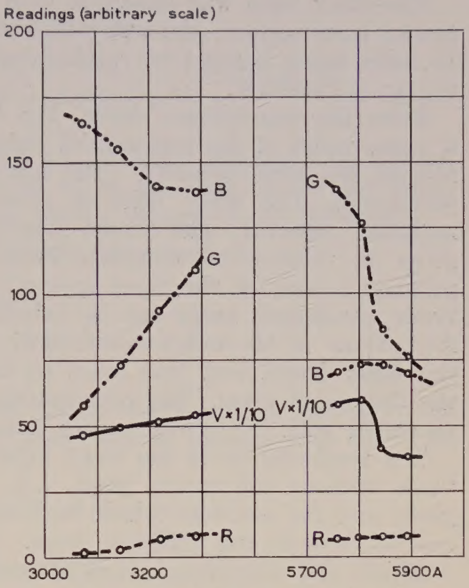

Fig. 6. Examples of measurements with the trichromatic method in the two ranges of wavelenght. V readings without colour filters, reduced tenfold.

the light owing to the dispersion in the glass prisms and the lens and also to reflexions at two additional surfaces. The lamp was adjusted in such a way that no colour dispersion could be observed with the eye. These adjusted distances between lamp, lens and slit where then carefully kept at all measurements. The magnitude of possibly remaining colour dispersion is evident from the following by comparing calculated values of the photocell current for the different colour filters with the corresponding measured values.

Calculation of the primary values, theory of corrections.

Depending on the angle of incidence, the energy measured for each point will form a greater or smaller part of the total energy for the particular wavelength, because all measurements were made with a constant height of slit in front of the photocell and the image of the entrance slit is astigmatic. The energy of the spectral line is distributed in accordance with Fig. 7 (11). All the primary values are corrected for astigmatism, the uncorrected values have no special interest.

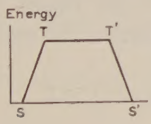

Fig. 7. Distribution of energy in a spectral line due to astigmatism.

The stray light was measured with a 931–A photocell. When used in a particular investigation, the obtained value of the stray light is directly applicable. In other cases it must be recalculated with regard to the spectral response of the actual receiver.

From the transmission curve, Fig. 4, the measured stray light is obtained as a mean value of the transmitted light, after the monochromatic residual transmission has been deducted. The mean value was calculated with the aid of a planimeter. The stray light is given in relation to the mean energy in the radiation interval. The chosen interval was 5725–5925 A, and the values are given in relation to $E(5825)$. From the measurements shown in Fig. 6 the primary values for the three spectral parts and the corresponding values in the lower wavelength range can be calculated, for instance, in per cent of $E(5825)$. All values in the range round 5825 A were obtained with didymium glass in the light beam, and thus must be corrected with regard to the absorption of the didymium glass. The corresponding values for the interval at 3150 A are measured with the compensating glass.

The recalculation of the stray light from the primary value so as to become valid without didymium glass, i. e. the correction for the absorption of the glass, and for receivers which have another spectral response than the 931–A, can be done in two different ways.

Either one can assume that the stray light has the same spectral composition as the incident light, or take into account that the spectral composition can differ from that of the incident light. In the latter case we must divide the actual spectral range into a sufficiently great number of intervals and analyze the contribution of stray light from each interval. We have confined ourselves to the three intervals given by the used colour filters, which is sufficient for our purpose. The recalculations are similar for both assumptions, with the exception that the investigated spectral range in the latter case is divided into three parts in determining the different factors. The following notations are used,

S stray light amount
Procedure a calc. under the assumption that the stray light has the same composition as the incident energy
Procedure b calc. taking its spectral composition into consideration
D integration over the whole range
B, G, R indicating the three ranges blue, green, and red, according to the filters; also spectral factors
c denoting actinic energy for the photocell used
d energy as received through the didymium absorption prism
f energy containing a colour filter function
$E(\lambda)$ energy radiation of the tungsten lamp, colour temp. 2800° K
$Z(\lambda)$ sensitivity curve of the photocell
$\tau(\lambda)$ transmission curve of the didymium prism

We note that the primary value of the stray light in the range 5825 A is measured with didymium glass, and in the range 3150 A without didymium glass.

$$S_{d,\,5825} = \frac{\int\limits_D E(\lambda)\,Z(\lambda)\,\tau(\lambda)\,d\lambda}{E(5825)\cdot Z(5825)} \qquad S_{c,\,3150} = \frac{\int\limits_D E(\lambda)\,Z(\lambda)\,d\lambda}{E(5825)\,Z(5825)}$$

The latter being consequently given in actinic energy for the photocell, the former must be recalculated, which gives

Procedure a:

$$S_{c,\,5825} = \frac{\int\limits_D E(\lambda)\,Z(\lambda)\,\tau(\lambda)\,d\lambda}{E(5825)\,Z(5825)} \cdot \frac{\int\limits_D E(\lambda)\,Z(\lambda)\,d\lambda}{\int\limits_D E(\lambda)\,Z(\lambda)\,\tau(\lambda)\,d\lambda} = S_{d,\,5825} \cdot f_1$$

Here the last factor, f_1, can be calculated if all quantities entering it are known. Z and τ can be measured and E is assumed to be the same as for the lamp. We obtain the stray light expressed in the actinic energy of the photocell.

Procedure b. With the three filters the following is measured.

$$S_{d,\,B} = \frac{\int\limits_D E(\lambda)\,Z(\lambda)\,\tau(\lambda)\,\tau_B(\lambda)\,d\lambda}{E(5825)\,Z(5825)}; \quad S_{d,\,G} = \cdots; \quad S_{d,\,R} = \cdots$$

where $\tau_B(\lambda)$ etc. is the transmission of the filters. Each part is corrected with regard to the absorption of the didymium glass, and in analogy with above we obtain

$$S_{f,\,B} = \frac{\int\limits_D E(\lambda)\,Z(\lambda)\,\tau(\lambda)\,\tau_B(\lambda)\,d\lambda}{E(5825)\,Z(5825)} \cdot \frac{\int\limits_D E(\lambda)\,Z(\lambda)\,\tau_B(\lambda)\,d\lambda}{\int\limits_D E(\lambda)\,Z(\lambda)\,\tau(\lambda)\,\tau_B(\lambda)\,d\lambda} = S_{d,\,B} \cdot f_2$$

and corresponding expressions for the green and the red ranges, with the factors f_3 and f_4. To obtain the total actinic energy we recalculate with regard to the absorption of the different filters, and the three parts are summed up

$$S_{c,\,B} = \frac{\int\limits_D E(\lambda)\,Z(\lambda)\,\tau_B(\lambda)\,d(\lambda)}{E(5825)\,Z(5825)} \cdot \frac{\int\limits_B E(\lambda)\,Z(\lambda)\,d(\lambda)}{\int\limits_D E(\lambda)\,Z(\lambda)\,\tau_B(\lambda)\,d(\lambda)} = S_{d,\,B} \cdot f_2 \cdot f_5$$

and correspondingly for the other ranges

$$S_{c,\,G} = S_{d,\,G} \cdot f_3 \cdot f_6 \qquad S_{c,\,R} = S_{d,\,R} \cdot f_4 \cdot f_7$$

The total actinic stray light is

$$S_c = S_{c,\,5825} = S_{c,\,B} + S_{c,\,G} + S_{c,\,R}$$

For the 3150 region, one measures $S_{f,\,B}$ etc. and gets a similar formula.

The stray light is now expressed in relation to the energy at 5825 A for a receiver which has the spectral response Z. If a receiver with a different spectral response, i. e. the eye with the visibility function $V(\lambda)$, is used, we obtain

$$S_{V,5825} = \frac{\int\limits_D E(\lambda)\,Z(\lambda)\,d\lambda}{E(5825)\,Z(5825)} \cdot \frac{\int\limits_D E(\lambda)\,V(\lambda)\,d\lambda}{\int\limits_D E(\lambda)\,Z(\lambda)\,d\lambda}\,\frac{Z(5825)}{V(5825)} = S_{c,5825} \cdot f_8.$$

Similarly, in the trichromatic method each part is recalculated and the parts are summed up.

The above calculations are made for one particular distribution of energy $E(\lambda)$ in the stray light. This distribution of energy is dependent on the incident energy, and in the procedure *a* the distribution is assumed to be equivalent to that of the incident energy. If the incident energy is changed to $E_1(\lambda)$, the expected stray light can be calculated as

$$S_1 = \frac{\int\limits_D E(\lambda)\, Z(\lambda)\, d\lambda}{E(5825)\, Z(5825)} \cdot \frac{\int\limits_D E_1(\lambda)\, Z(\lambda)\, d\lambda}{\int\limits_D E(\lambda)\, Z(\lambda)\, d\lambda} \frac{E(5825)}{E_1(5825)} = S_c \cdot f_9$$

We obtain a conception of the distribution of the stray light if we compare the three terms for the measurements with the filters with the corresponding integrals obtained for a known distribution of energy. In this comparison, three spectral factors are obtained which indicate the composition of the light in relation to the known distribution. The factors are calculated in the following way

$$E_{\text{total}} = \int\limits_D E(\lambda)\, Z(\lambda)\, d\lambda$$

$$E_B = \int\limits_D E(\lambda)\, Z(\lambda)\, \tau_B(\lambda)\, d\lambda; \; E_G = \cdots; \; E_R = \cdots$$

$$B = \frac{S_{c,B} \cdot E_{\text{total}}}{S_c \cdot E_B} \qquad G = \frac{S_{c,G} \cdot E_{\text{total}}}{S_c \cdot E_G} \qquad R = \frac{S_{c,R} \cdot E_{\text{total}}}{S_c \cdot E_R}$$

In the higher region, the measurements are made with the didymium glass, in which case the transmission of the glass enters into the integrals and S_c is changed to S_d. If the stray light has the same distribution of energy as the incident light, this ratio obviously is unity. A value greater than 1 means, that the stray light contains more energy, seen relatively, within this interval than the incident light, while a value smaller than 1 shows the opposite. Thus, if the incident light is "white", a displacement of its distribution of energy has taken place and it has obtained a particular colour.

Determination of the recalculation factors, measurements and calculation

For the calculation of the above factors it is necessary to know the energy distribution, sensitivity curves of the receivers, and the transmission curves of the filters. The curves for three coloured filters B, G, and R are given in Fig. 5. The density curve of the didymium glass is given in Fig. 8.

The distribution of incident energy is obtained from the colour temperature of the lamp, 2800° K, corresponding to a black body temperature of 2467° K. From Planck's radiation law, the emission coefficients for tungsten, and the transmission curves for the UV filter, Fig. 2, the incident energy is calculated for constant $d\lambda$. The curve is found in Fig. 9, in which the values are normalized so that $E(5825) = 100$.

To calculate the actinic energy curve of the receiver, it is necessary to know its spectral response. Curves are given for the photocells in RCA's data book. Photocells of the same type are, however, rather individual with regard to spectral and absolute sensitivity, and consequently it was necessary to make measurements on the tubes. In the integrals the product $E(\lambda)\, Z(\lambda)$ enters, and consequently it is sufficient to determine this. The determination of the product

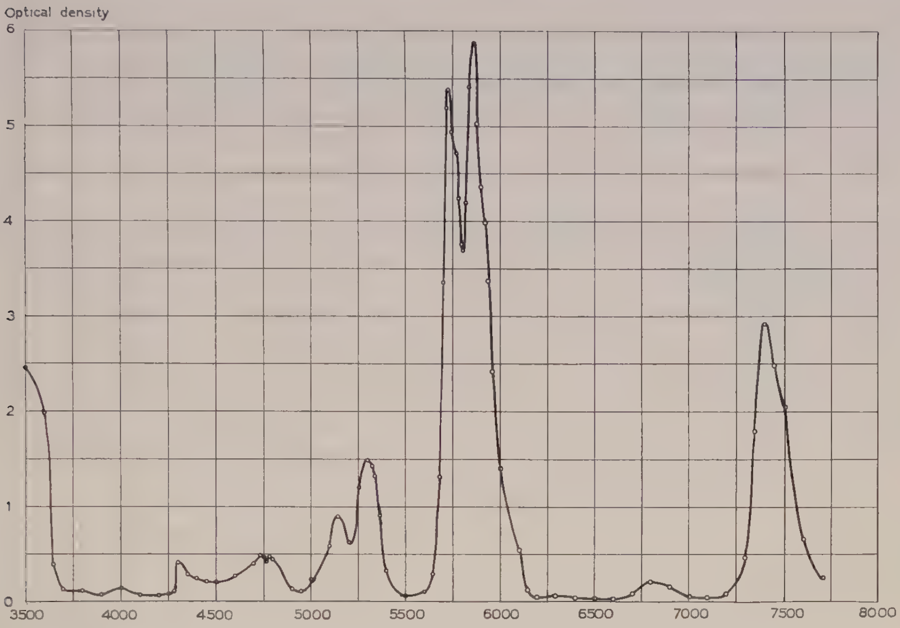

Fig. 8. Density curve of the didymium prism corrected for reflexion by means of the compensating prism.

was made in a mirror double monochromator, Kipp & Zonen, Type L 30. The same tungsten lamp as in the measurements of the stray light was used. The instrument contains 10 mirrors and one mirror for the projection of the lamp onto the entrance slit, i. e. the beam is subject to 11 reflexions. The photocell current as a function of the wavelength was determined and the values were recalculated to constant $d\lambda$. The mirrors are aluminized, and corrections must be made for their different reflexion coefficients for different wavelengths, which values were taken from a curve according to STRONG (12). This curve is in good agreement with values obtained by other authors (13, 14). These actinic curves, normalized to 100 for $E \times Z\,(5825)$, are given in Fig. 10 for the 931-A photocell, and in Fig. 11 for 1P22. These figures contain all the curves for the photocells.

Other necessary curves are the actinic curve with the didymium glass and actinic curves with and without didymium glass for the three filters. All these curves are obtained by multiplying the measured actinic curves by the respective transmission curves, measured in a Beckman spectrophotometer. Figs. 5 and 8.

In measuring with the photocell the current is proportional to the energy, corresponding to the actinic curve. This actinic energy is obtained from the curves by graphical integration. Table 1 contains values calculated from the curves in this way and measured in the incident light.

Considering how the different values of the table have been obtained, the calculated as the final result of three measurements and one graphic integration, which all have a certain error, as for instance in the measurements 1 to 2 per cent, the agreement is fairly good. From the measurements with the three filters it is also evident that no difference occurs in the composition of the light,

Table 1

Actinic energies, measured and calculated. Photocell 931–A.

	Without extra filter	Filter		
		BG 12	VG 1	RG 2
Measured values without did. glass	1 000	215	201	22.2
D:o with did. glass	486	141	78	18.0
value without did. glass / value with did. glass	2.05	1.53	2.58	1.23
Calculated values without did. glass	1 000	223	198	21.2
D:o with did. glass	480	150	75	16.9
value without did. glass / value with did. glass	2.08	1.49	2.64	1.25
Relation between measured and calculated values				
Without did. glass	1.00	0.97	1.01	1.05
With did. glass	1.01	1.06	1.04	1.07

due to a possible dispersion in the lens and glass prisms. The calculated values are based on the transmission curve of the didymium glass. In measuring this curve the reflexions at the boundary surfaces have been compensated. A small difference in the reflexion enters the measurement as a change in optical density, which gives rise to a fairly large error, where the density is small, specially as it is multiplied three times. The agreement of all results proves that this severe error has been of negligible amount.

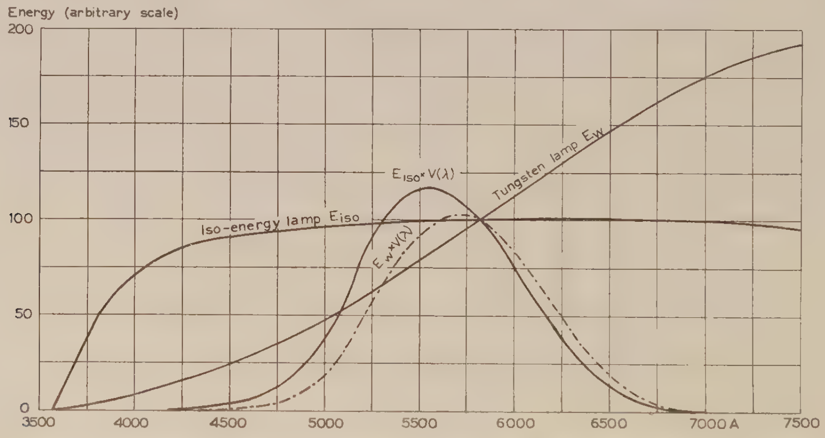

Fig. 9. Energy distribution curves for incident light from tungsten lamp and iso-energy lamp and these curves multiplied by the international eye visibility curve.

From Table 1 and the curves in Figs. 9, 10, and 11, the recalculation factors mentioned in the preceeding paragraph, are obtained. The wavelength range is limited to cover 3600–7400 A. Within this range the limits for three filters are put at 4800 A and 6250 A.

The recalculation factors for the absorption of the didymium glass can either be taken from measurements in the incident light or from the calculated values. The measured values ought to be somewhat more reliable than the calculated, and so they have been used.

Table 2

Recalculation factors f_1–f_4 for the energy absorbed by the didymium glass.

Range	Factor marked	Photocell	
		931–A	1P22
a. White light, radiation of tungsten lamp with UV filter	f_1	2.05	1.98
b. Filter BG 12, blue..............	f_2	1.53	1.53
» VG 1, green.............	f_3	2.58	2.54
» RG 2, red	f_4	1.23	1.31

The recalculation according to procedure *a*, which presumes that the stray light has the same spectral composition as the incident light, gives the stray light in relation to the actinic energy of the photocell. To obtain this by procedure *b*, a further recalculation for the absorption of the filter is made.

These factors can be obtained by two methods, either from the ratio between the calculated energies or from the measured energy and the corresponding part of the calculated actinic energy of the photocell. The first case may be more reliable, as it depends only on the transmission curves of the filter.

Table 3

Recalculation factors f_5–f_7 for energy, absorbed by the filters.

Filter range	Factor marked	Photocell	
		931–A	1P22
3600–4800 A, BG 12	f_5	1.71	1.73
4800–6250 A, VG 1	f_6	2.93	3.36
6250–7400 A, RG 2	f_7	1.90	1.59

Transfer between different receivers and radiation sources

The final aim of this investigation is to state values for the stray light of the grating in relation to the main light i. e. to obtain the relative magnitude of the disturbance. Of course, this must be different, depending on the receiver used for the grating. Therefore we have stated the value of three different cases: photomultiplier 931–A, the cell which is now included in RCA's standard series, black body receiver, which is practically realized in the thermopiles, and the eye (15).

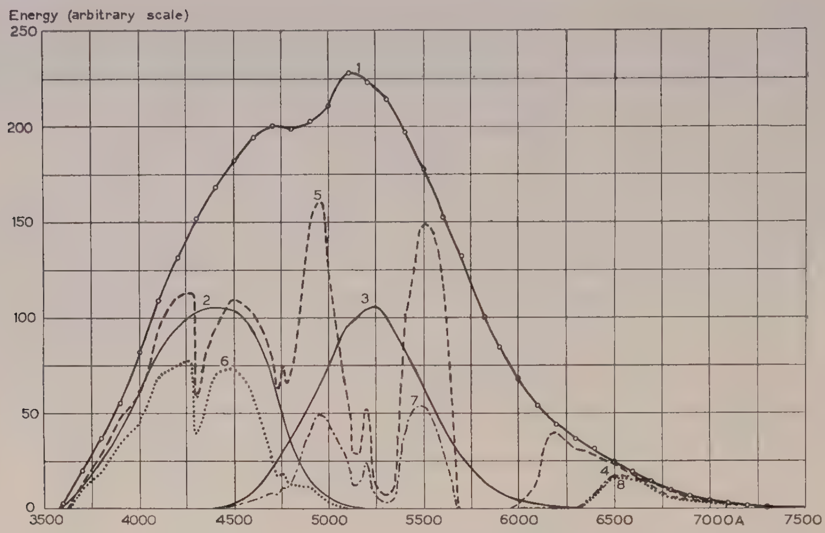

Fig. 10. Actinic energy curves for the 931—A cell

1) ——— $E_W Z$, 2) ——— $E_W Z \tau_B$, 3) ——— $E_W Z \tau_G$

4) —··—··— $E_W Z \tau_R$, 5) — — — — — — — $E_W Z \tau$ 6) ········ $E_W Z \tau_B \tau$

7) —·—·—·— $E_W Z \tau_G \tau$ 8) ········ $E_W Z \tau_R \tau$

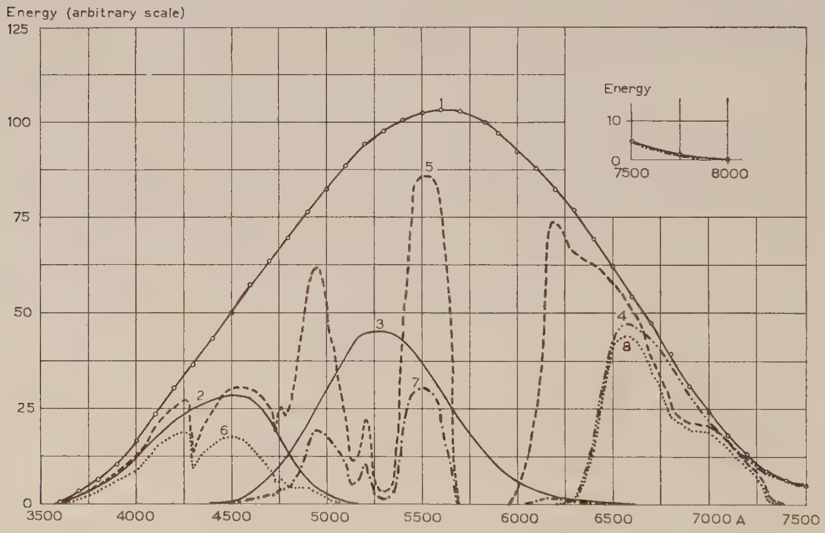

Fig. 11. Actinic energy curves for 1P22 cell. The same notations as in Fig. 10.

From Fig. 9, 10 and 11 we can get the recalculation factors for these receivers with different lamps, listed in Table 4. The iso-energy lamp is only a theoretical construction and the recalculation to its energy radiation is to be preferred as an intermediate step, as one can easily pass from one to the other.

Table 4

Recalculation factors for primary values, corrected for the absorption of didymium glass, measured with tungsten lamp, colour temperature 2800° K. Photocell 931–A.

	Procedure *a*	Procedure *b*		
	3600—7400 A	3600—4800 A	4800—6250 A	6250—7400 A
I. Actinic energy	1	1.71	2.93	1.91
II. Black body receiver tungsten lamp	0.85	0.216	1.57	15.5
III. Black body receiver, iso-energy lamp	0.91	1.04	1.91	9.5
IV. V (λ, int), iso-energy lamp	0.34	0.039	1.51	0.66
V. V (λ, int), tungsten lamp	0.29	0.014	1.29	0.96

Comparison between the results given by the two procedures

A detailed discussion of all the material gathered during the test of this method cannot be given here; we refer to a special report (16). In Table 5 is given an excerpt of results. In the report just mentioned numerous comparative values with the two different photocells are contained.

Table 5

Measurements on grating 172037, incident angle 0°. All values are in per cent of $E(5825)$, corrected for astigmatism. Range 5825 A.

	Procedure *a*	Procedure *b*
I. Actinic energy	0.630	0.631
II. Black body receiver tungsten lamp	0.537	0.400
III. Black body receiver iso-energy lamp	0.574	0.484
IV. V (λ, int), iso-energy lamp	0.207	0.211
V. V (λ, int), tungsten lamp	0.181	0.181
Spectral factors: *B*		1.00
G		1.03
R		0.50

The relatively great discrepancy between the values for black body receiver is due to the low spectral factor for the red. The red contribution is 0.16 per cent. In procedure *a*, there is calculated with twice as great a contribution of it as in procedure *b*, giving the actual value. Regarding this, the difference is quantitatively explained.

The correspondance between the sensitivity curve of the receiver and the spectral factors on one side, and the error in using the approximate procedure *a* instead of procedure *b* on the other, is further seen from Tables 6 and 7. When, for instance, the *G* factor is less than unity, the procedure *a* gives too high values.

Table 6

Values for grating No. 157674. All values referred to per cent of E (5825). Tungsten lamp, colour temp. 2800° K. Region 5825 A.

Incident angle, degrees	Side	Mean value with didymium filter	Spectral factors			Primary values with didymium filter			Stray light					
									Photocell 931—A		Black receiver		V (λ, int)	
			B	*G*	*R*	*B*	*G*	*R*	*b*	*a*	*b*	*a*	*b*	*a*
0	I	0.056	0.54	1.38	0.45	0.0088	0.0125	0.0009	0.120	0.115	0.071	0.098	0.043	0.033
	II	0.095	0.74	1.17	0.53	0.0204	0.0178	0.0019	0.192	0.193	0.114	0.155	0.062	0.056
17	I	0.056	0.67	1.24	0.60	0.0109	0.0112	0.0013	0.116	0.115	0.073	0.098	0.039	0.033
	II	0.082	0.78	1.06	0.57	0.0186	0.0140	0.0017	0.158	0.168	0.096	0.143	0.049	0.048

Table 7

Values for grating No. 157674. All values referred to per cent of E (5825). Tungsten lamp, colour temp. 2800° K. Region 3150 A.

Incident angle, degrees	Side	Mean value	Spectral factors			Primary values without didymium filter			Stray light				Comments
									Black receiver		V (λ, int)		
			B	*G*	*R*	*B*	*G*	*R*	*b*	*a*	*b*	*a*	
0	I	0.064	1.18	0.75	0.40	0.0181	0.0106	0.0006	0.038	0.054	0.015	0.018	
	I	0.047	1.41	0.72	0.19	0.0140	0.0068	0.0002	0.017	0.040	0.009	0.013	masked
	II	0.076	1.23	0.81	0.80	0.0204	0.0126	0.0014	0.045	0.061	0.018	0.022	
17	I	0.071	0.34	0.79	0.48	0.0205	0.0112	0.0008	0.039	0.061	0.016	0.020	
	II	0.074	1.26	0.82	0.83	0.0198	0.0122	0.0014	0.045	0.063	0.017	0.021	

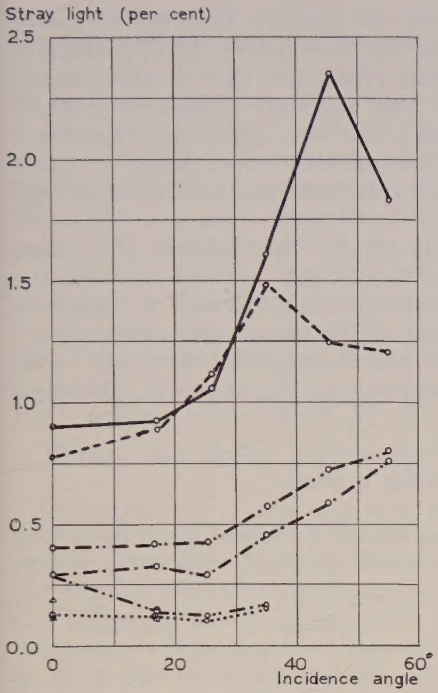

Fig. 12. Amounts of stray light in the wavelength region about 5825 A, related to actinic energy for the 931—A cell, first order with different angles of incidence.

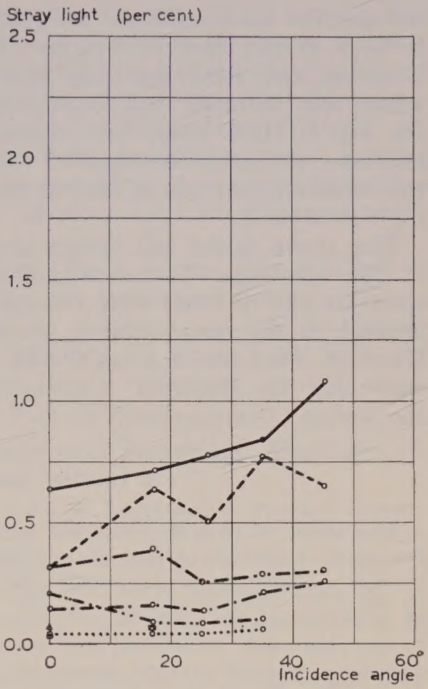

Fig. 13. Amounts of stray light in the wavelength region about 3150 A, related to actinic energy for the 931—A cell, first order with different angles of incidence.

——— Replica, side II. — — — — — — Replica, side I. — — ·· — — ·· — — ·· Original 172037, side II. — · — · — · — Original 172037, side I. — ·· — ·· — ·· Original 157673, side II. ·········· Original 157673, side I. △ Original 157674, side II. ☐ Original 157674, side I.

Comments on measurements at different gratings

The full material is gathered in (16). As examples may here serve Tables 6 and 7, containing values of one grating, and Figs. 12 and 13, giving the variation of the stray light, only expressed in actinic energy, with the incident angle. Some general comments may be of value.

The American replica grating, which in these measurements was screened to about 60 per cent in order to eliminate non-homogeneous parts, appears irregular, while grating No. 172037 and the new blazed gratings are more regular. Further they have lower absolute values. As seen from the curves, the total amount of stray light generally increases rather irregularly with increasing angle of incidence. However, no other regularity can be traced.

The spectral factors show which part of the visible range contributes most to the stray light. In the range 5825 A the green factor is the largest, and in the other range the blue, which is not surprising regarding some of the origins of the stray light. As an example of a stray light from a specific reason, we mention an observation on gratings 157673 and 157674. Here the red factor is large in the ultraviolet range. When observing the grating 157674 visually, a strong red stray light was seen, which came from the part of the grating, where the diamond had begun the ruling. The boundary is sharply marked, see Fig. 6. This range was screened, whereby the total stray light decreased and the red part decreased to the half of its previous value. Table 7. After the screening, the curve for red in Fig. 6 did not show the increase of the red part at 3150 A.

The above tables and curves give a picture of the stray light in two ranges of the spectrum. The measurement of the stray light in ranges outside the spectrum can be made with common photometric methods. One can, for instance, measure in the range 3150 A, where no energy of this wavelength exists, with a luxmeter, for instance Jobin-Yvon's Nitomètre, and thereupon in the range above and below the spectrum, whereby these measurements can be put in relation to the earlier. Compare (17).

A routine test method for gratings

The origin of this idea was the necessity for a standard method for investigating the stray light properties of qualified spectroscopic gratings, sufficiently simple to be accomplished with the apparatus a spectroscopic laboratory always has at its disposal and simple additional details. The aim of this investigation was to develop such a method and to make an allround investigation of the approximations involved in the recommended method. Recommendations are given in the following. For the present, the method concerns gratings for use in the visual and nearest ultraviolet range.

The grating is illuminated by continuous light from a tungsten lamp of colour temperature 2800° K, the ultraviolet part of which has been absorbed, so that no radiation from the spectrum of the second order overlaps the first order spectrum below 6000 A, i. e. the filter must absorb all radiation below 3000 A. Use a didymium glass prism with two sides well polished and sufficiently parallel, with an absorption in the yellow range corresponding to an optical density of about 5, and a compensating prism of clear glass of the same form, which gives the light beam the same geometrical properties as the prism of didymium glass. Place these prisms in turn in the light beam, preferably in front of the entrance slit, which is made broad, and measure the current of a photocell, or a photomultiplier with a broad entrance slit, which is placed in a focussed spectrum of the first order at the wavelength 5825 A. Provided that the spectral transmission of the didymium glass is sufficiently small, as recommended here, the amount of the stray light is obtained as the ratio between the measured currents of the photocells, multiplied by the factor larger than 1, which corrects the light incident through the didymium glass on the grating, to the light which the lamp, if unfiltered, would have given. — If of interest, move the photocell to the near UV region and perform as described in this paper.

If the measurements are made with the same photocell which is to be used in connection with the grating, the obtained value is directly applicable. If another receiver, for instance another photocell, a black body receiver, or the eye, is to be used, the value can be recalculated by using the known spectral curves according to procedure *a*, given in the foregoing.

A corresponding recalculation can be undertaken for other light sources. For a spectral lamp with the intensity collected in a few lines or groups of lines, the integral over a continuous spectrum is replaced by a summation with regard to the line intensities and a photometric determination of the total light flux.

The measurements must be made on the angles of incidence for later use and in the planned mounting of the grating. When investigating stray light or resolving power, it is necessary to observe the possibility of screening bad parts. Often the bad parts from the point of view of stray light are also those which reduce the resolving power.

According to the investigations made here, the approximation involved in procedure *a* that the stray light radiation has the same spectral composition as the incident light, is permitted up to a few ten per cent, and it is thus generally fully acceptable for determining the influence of stray light with the necessary accuracy. Only in one of the cases here investigated, i. e. with black body receiver, were values 50 per cent too high obtained.

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